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Research Article

Laser Induced Graphene Fabrication and its Application in Flexible Strain Sensors

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Abstract

In this paper, nano-patterning of graphene on polyimide films by CO_2 laser with a wavelength of 10.6μm and a power of 40W is presented. By analyzing SEM images of laser-induced graphene with different morphologies obtained at different power levels, the optimum power to obtain laser-induced graphene was obtained at 2.9 W with energy density of 29 J/cm^2, scanning speed of 100 mm/s and focal diameter of 0.1 mm.One method to fabricate a flexible sensor based on LIG is presented.

Keywords: laser, graphene, polyimide, flexible sensor, power

Introduction

Graphene is a new two-dimensional carbon nanomaterial, which has attracted special attention in the field of nanomaterials. Graphene is a two-dimensional honeycomb structure composed of densely packed carbon atoms. The simplest graphene is a monolayer structure, but there are also two-layer graphene or multilayer (less than 10 layers) graphene. Graphene has many applications due to its excellent optical, thermodynamic and mechanical properties, high electron mobility, large specific surface area, and unique electro-optic properties [1].

Traditional graphene preparation methods include chemical reduction, mechanical exfoliation, chemical vapor deposition, and organic synthesis. The advantages of these methods are the high quality of graphene, which can be produced in large quantities. However, these methods have disadvantages such as the complexity, high cost and environmental unfriendliness of the graphene fabrication process.

Recently, a new method for the direct preparation of graphene by irradiating laser light to polyimide thin films and other polymeric polymers has been developed. The advantages of this method are low cost, high speed, and the ability to produce graphene with different textures and environment friendly [3-8]. This method has great potential for applications in many fields, including flexible sensor electrode fabrication, due to its unique advantages.

We have prepared a flexible sensor electrode capable of detecting Escherichia coli O157:H7 by incorporating gold and silver nanoparticles into laser-induced graphene and confirmed that the sensor electrode has not changed after more than 500 bending tests [4]. Zhiheng You et al. fabricated laser-induced

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noble metal nanoparticle-graphene composites enabled flexible biosensor for pathogen detection [3]. Ji Li et al. also investigated an effective method to pattern graphene films with nanoscale features [7].

Some researchers have prepared low-layer porous graphene using CO_2 laser scanning of commercial polyimide films in a assist gas atmosphere [8].

In summary, the research on laser-induced graphene fabrication is still in its infancy and there are many challenges to be solved. In this paper, the optimal power value for graphene fabrication by scanning CO2 laser into polyimide films is theoretically determined. Next, we introduce a method to fabricate flexible sensor electrodes using laser-induced graphene.

Laser induced graphene preparation

1) Experimental setup

Figure 1 shows the computer-controlled CO_2 laser cutter (VLS 3.50, a universal laser system). Using this device, LIG was prepared by scanning the laser light onto a polyimide film (thickness of 0.125mm). The maximum power of the CO_2 laser is 40 W, the wavelength is 10.6 μm, and the maximum spot diameter is 0.1 mm.

The maximum laser frequency is 5 kHz and the maximum scanning speed is 400 mm/s.

2) Power determination for laser-induced graphene fabrication

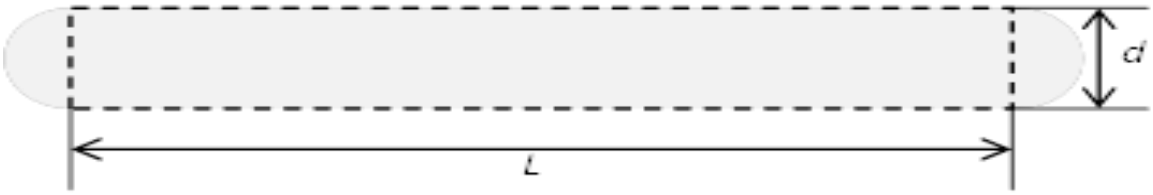

Fig.1 Laser scanning path

The path through which the focal point of the laser beam is crossed is shown in Fig. 1. Then the radiant energy of the laser beam, E, can be obtained by

$$E = \frac{W}{S} \approx \frac{Pt}{dL} \approx \frac{P}{dv} \qquad (1)$$

where W is the total work done by the laser beam, S is the scanning area, P is the laser power, t is the scanning time, d is the focal spot diameter of the laser beam, and v is the scanning speed.

As shown in Fig. 2, the morphology of laser-induced graphene varies greatly with the laser power value. As the E value increases, the morphology of the resulting graphene changes, and when less than 7 J/cm^2, the polyimide film does not carbonize, so that graphene does not form.

Since the E value was higher than 7 J/cm^2, the polyimide film started to carbonize and the graphene was formed, as shown in the figure, the pores were very small and part of the polyimide film was still not carbonized. The laser-induced graphene formed at E = 29 J/cm^2 has a stacked structure with a large increase in porosity. At E= 47 J/cm^2, the laser-induced graphene is transferred from the flake to the fiber structure, while at E = 70 J/cm^2, the structure of graphene loses its regularity and has a disordered ordering.

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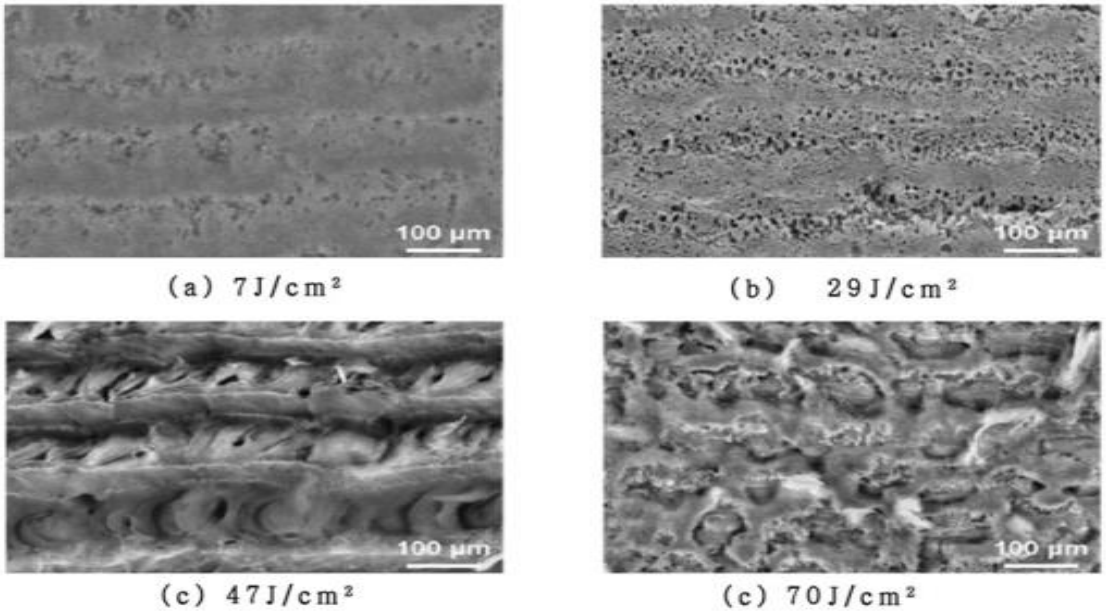

Fig.2 SEM images of laser-induced graphene obtained at different energy densities.

When the structure of laser-induced graphene is a layered structure (E = 29 J/cm^2), the adhesion of the formed graphene is stronger than the remaining three cases, which is advantageous for use in the next process. As shown in Eq (1), the scanning speed, spot diameter, and energy are required to determine the optimum power for the fabrication of laser-induced graphene.

In our case, d = 0.1 mm, so the laser power P and the scanning speed v are important parameters to determine the morphology of laser-induced graphene. When v = 100 mm/s, E = 29 J/cm^2, d = 0.1 mm, according to Eq. (1), P = 2.9W is obtained. As the scan rate increases, the power value increases.

Fabrication of flexible sensors

The existing traditional sensors are not flexible, therefore cannot be applied to objects with different surface shapes, such as the human body. Therefore, we fabricated a flexible sensor that can be attached to any curved surface using laser-induced graphene.

The transfer of the obtained laser-induced graphene to a flexible substrate is a key technique in the fabrication of flexible sensors. Laser-induced graphene is a three-dimensional porous foam structure, so that the elastic body in the liquid state, which is not solidified, can penetrate completely. We fabricated a flexible laser-induced graphene electrode using a polydimethylsiloxane liquid.

The fabrication of flexible laser-induced graphene sensor electrodes is as follows.

- A polyimide thin film specimen with the size of 1.5×7cm was fixed on a glass plate using water-soluble double-sided patch.
- The graphene electrode morphology to be prepared was fabricated by scanning the laser beam onto the film sample using the laser cutting machine.
- The thin film sample prepared with laser-induced graphene was immersed in ionic water for 2 hours to remove the aqueous double-sided patch and separate it from the glass plate.
- The thin film sample was placed in a test vessel and the surface of the laser-induced graphene-formed part was sprayed with polydimethylsiloxane.
- Then, the polydimethylsiloxane-impregnated film sample was placed in a thermostatic drying oven

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and the temperature was set to 80 °C and dried for 20 min.

- After drying, the thin film sample was removed from the furnace and the polydimethylsiloxane-solidified graphene part was separated from the film, resulting in a laser-induced graphene sensor electrode with the desired electrode pattern.
- Next, connecting the electrode leads, the sensor fabrication is completed.

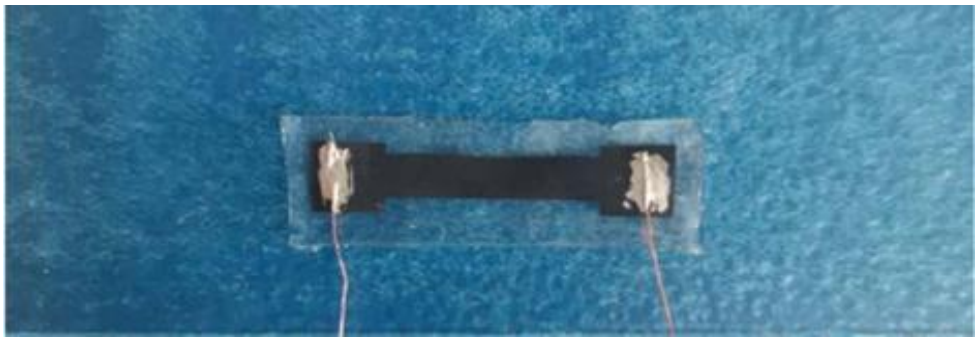

Fig.3 Laser induced graphene electrode

Figure 3 shows the laser-induced graphene electrode fabricated by the above process.

Conclusion

We first determined the optimal laser power for LIG production using a CO_2 laser. The power value depends on the scan rate, in our case, it was $P = 2.9$ W when $d = 0.1$ mm, $v = 100$ mm/s, $E = 29$ J/cm^2,.

Next, we represent a method to fabricate a flexible sensor using LIG. Using this method, we can fabricate graphene electrodes that can be attached to curved objects of arbitrary shape. The fabrication technique can be widely used to fabricate sensors that measure various properties of objects with complex surfaces that are difficult to use with conventional sensors.

References

1. *Liu C., Li F., Ma L. P., Cheng H. M.* Advanced materials for energy storage // Advances in Materials 2010. V. 22. P. E28-E62.
2. *Marc Currie, Joshua D. Caldwell, Caldwell, Francisco J. Bezares, Jeremy Robinson, Travis Anderson.* Quantifying pulsed laser induced damage to grapheme. // Applied Physics Letters. 2011. V. 99. 211909.
3. *Zhiheng You, Qiming Qiu, Huayun Chen, Yuyan Feng, Xiao Wang, Yixian Wang, Yibin Ying.* Laser-induced noble metal nanoparticle-graphene composites enabled flexible biosensor for pathogen detection // Biosensors and Bioelectronics. 2019. doi.org/10.1016/j.biso.2019.111896
4. *Ana R. Cardoso, Ana C. Marques, Lidia Santos, Alexandre F. Carvalho, Florinda M. Costa, Rodrigo Martins, M. Goreti F. Sales, Elvira Fortunato.* Molecularly-imprinted chloramphenicol sensor with laser-induced grapheme electrodes // Biosensors and Bioelectronics. 2018. doi.org/10.1016/j.bios.2018.10.015
5. *Wenjie Yu, Yunyan Peng, Lijun Cao, Weiwei Zhao, Xiaoqing Liu.* Free-standing laser-induced grapheme films for high-performance electromagnetic interference shielding // Carbon. 2021. Vol. 183. P. 600-611.
6. *Luong Xuan Duy, Zhiwei Peng, Yilun Li, Jibo Zhang, Yongsung Ji, James M.* Tour. Laser-induced graphene fibers // Carbon. 2017. doi.org/10.1016/j.carbon.2017.10.036

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7. *Ji Li, Gary J. Cheng, Rongjun Zhang, Hanqing Jiang.* Laser shock induced nano-patterning of graphene // Proceedings of the ASME 2012 International Manufacturing Science and Engineering Conference MSEC2012, Notre Dame, Indiana, USA, 2012. 4-8.
8. *Ram K. Gupta.* 3D Graphene. Springer, 2023. 434.

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